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NASA GENERAL WORKING PAPER NO. 10,052

APOLLO-X RADIATION HAZARD ANALYSIS

N70-75425

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

June 4, 1965

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NOTICE

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APOLLO-X RADIATION HAZARD ANALYSIS

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By
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SUMMARY

This paper is an analysis of the expected radiation dose for one proposed Apollo-X mission. This mission is a 19,237 nautical mile synchronous orbit of 34 days duration. The dose from Van Allen radiation is calculated, and the effect of solar particle events on the probabilities of mission success and crew safety is discussed.

INTRODUCTION

The Apollo-X space station is a spacecraft having the configuration of the original Apollo vehicle with an additional laboratory module attached to the top of the command module. The laboratory is shaped somewhat like a cylinder with rounded ends. (See fig. 1.)

This vehicle will be flown in a synchronous orbit of 0° inclination at an altitude of 19 237 nautical miles. The duration of the mission at this altitude is expected to be 34 days. The crew is expected to spend 14 hours per day in the laboratory and 10 hours per day in the command module. The preliminary mission profile is shown in table I.

Apollo-X will encounter radiation in transferring from a near-earth orbit to the synchronous orbit, and in the synchronous orbit itself. In addition to Van Allen radiation, which is certain to be encountered, there will be an additional hazard from solar particle events, since the rigidity (momentum per unit charge) necessary for the particles to penetrate the earth's magnetic field is very low (approximately 0.20 BV) at 19 237 nautical miles. A rigidity of 0.20 BV corresponds to a particle energy of 22 MeV. This analysis will consider the hazard from solar particles of energies greater than or equal to 30 MeV, which is the cutoff energy for the spacecraft shielding.

DOSE ANALYSIS

Van Allen Radiation

Apollo-X is scheduled to fly in the 1969-71 time period. This will coincide with the next solar maximum, and the particle intensities in the Van Allen belts will be considerably different from what they are now. Even at present, there are large daily fluctuations in intensity due to variations in magnetic activity caused by the sun. The intense artificial electron belt created in July 1962, will have decayed to a great extent, assuming that there are no new nuclear detonations. These considerations make it possible to give only a crude estimate of the dose from these particles. As will be shown, however, the dose from the Van Allen belts will have little effect on crew safety and mission success. (The probability of crew safety, abbreviated as C.S., is the probability that the crew will not receive a dose greater than or equal to the recommended dose limit. The probability of mission success, abbreviated as M.S., is the probability that the crew will successfully complete all tasks of the mission and still not exceed the dose limit. Note that mission success includes crew safety. These definitions, as used here, apply only to radiation hazards.)

In transferring to the synchronous orbit, the vehicle will encounter proton and electron fluxes in the inner belt, and electron fluxes in the outer belt. A good approximation of the fluxes encountered in the inner belt has been obtained by means of the Goddard Orbital Flux Code, developed at Goddard Space Flight Center by Dr. Wilmot Hess and his coworkers (ref. 1). This program accepts as input data the injection parameters for the vehicle trajectory of interest and calculates the particle fluxes encountered by the vehicle at various positions along the trajectory. The particle flux grids which the program uses were made up from data obtained by various experimenters with satellites and sounding rockets.

The fluxes calculated by the Goddard program were used as input data to dose calculations for this paper. By means of computer programs which calculate normalized particle doses for various shielding configurations and spectral forms, one obtains the total dose by taking the product of the normalized or unit flux dose and the total flux. It turns out that the skin dose inside the command module in going from 100 to 19 327 nautical miles at 0° latitude is 1.9 rem. This is from primary protons, electrons and bremsstrahlung.

When the vehicle is in the synchronous orbit, the Van Allen radiation dose will be due almost entirely to primary electrons and bremsstrahlung. The protons at this altitude are for the most part in the low energy (100 keV - 10 MeV) range. The spectrum used in calculating the electron dose at 19 327 nautical miles is an extrapolation of a spectrum obtained by Frank, Van Allen, and coworkers with detectors on Explorer 14 (ref. 2). There is considerable uncertainty concerning the spectrum at high altitudes in the outer belt, but it has been established that it is quite steep in the range from 1.5 to 5 MeV (ref. 3). Since the exact shielding of the laboratory module was not available at the time that this study was done, the approach used in calculating dose was to assume a spherical geometry with an average thickness of 1.45 gm/cm^2 of aluminum. This will give a conservative value for the dose because it does not take into account all of the shielding which will actually be present. The total electron doses, primary and bremsstrahlung, are shown in table II for both the laboratory and command module. Adding the doses in table II to that received in passing through the belts, the total dose from Van Allen radiation is, therefore, 1.9 + 68.2 = 70.1 rem.

The average yearly skin dose limit for astronauts is 325 rem. The dose from the Van Allen belts is far below this, so it is apparent that the belts do not present a threat to crew safety or mission success.

Solar Particles

In assessing the hazard from solar particle events, it is necessary to think in terms of the probability of occurrence of these events. Using the data from the previous solar cycle, one can determine the probability distribution of event sizes for the mission length of interest (ref. 4). The normalized solar particle (proton and alpha) dose inside the command module has been determined by extensive machine calculations performed at the Manned Spacecraft Center (ref. 5). The probability distribution of solar particle event sizes and the normalized dose are necessary in calculating mission reliabilities as far as solar particle hazards are concerned.

When the Apollo-X mission takes place, there will be an operational warning network which will be capable of giving as much as 4 hours warning that a solar particle event is going to occur (ref. 6). It will also be able to predict within a factor of three what the total flux of the event will be. Therefore, this analysis is based on the assumption that the crew will be aware that an event is going to occur and will either (1) spend the duration of the event in the command module and resume normal duties afterwards, or (2) abort the mission completely.

The normalized dose from solar particles in the command module is $2.97 \times 10^{-8} \frac{\text{rem-cm}^2}{\text{particle}}$. At present the maximum permissible emergency dose to the skin is 700 rem. In order to obtain the probability of crew safety, it is first necessary to calculate the flux which would give a dose equal to the dose limit. This is done as follows:

$$\frac{(700 - 70)\ \text{rem}}{2.97 \times 10^{-8}\ \frac{\text{rem-cm}^2}{\text{particle}}} = 2.1 \times 10^{10}\ \text{particle/cm}^2$$

This is the flux necessary to give a dose of 630 rem in the command module. The dose from the Van Allen belts has been subtracted because it is certain to be received; hence the emergency dose limit should be reduced accordingly.

Figure 3 is the probability distribution of total flux for a mission of 34 days. Figure 4 is basically the same distribution, except that the solar particle flux has been converted to skin dose in the command module. From figure 3, the probability of encountering 2.1×10^{10} particles/cm^2 or more is found to be 0.002. Therefore, C.S. = 1.000 - 0.002 = 0.998. This assumes that the crew rides out the event in the command module. A higher reliability could be obtained in one of two ways. The first is to add shielding to the command module. The second would be to abort. Assuming that the warning system can give 4 hours warning, the vehicle could be brought down to an altitude at which the crew would be protected by the earth's magnetic field. In this case the probability of crew safety would be 1.0 for radiation.

If the warning system indicates that an event with a flux of 2.1×10^{10} is going to occur, the actual flux may be as low as $2.1 \times 10^{10}/3$ or 7.0×10^9. Conversely, a predicted flux of 7.0×10^9 may be as high as 2.1×10^{10}. Hence, the probability of mission success is determined by the probability of an event equal to or greater than 7.0×10^9 particles/cm^2 which is 0.007. Assuming that the mission is aborted when this flux is predicted, then M.S. = 1.000 - 0.007 = 0.993. This is the worst case as far as mission success is concerned. The crew could stay in the command module until the event is over, in which case M.S. would be somewhat difficult to determine because the crew would be in the command module at times when they would normally be in the laboratory. Mission success would, therefore, be adversely affected because the crew would be forced to omit some of their scheduled duties. In any case, M.S. would be no worse than 0.993.

CONCLUSIONS

The crew of the Apollo-X vehicle will receive a radiation dose to the skin from the Van Allen belts which is conservatively estimated in this paper to be 70.1 rem. This is far below the yearly average skin dose limit of 325 rem. There is also a certain probability that Apollo-X will encounter radiation from one or more solar particle events. From the probability distribution of particle flux for a 34-day mission, it has been determined that, at worst, the probability of crew safety is 0.998 and the probability of mission success is 0.993.

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TABLE I.- PRELIMINARY MISSION PROFILE FOR APOLLO-X

1.	Launch due east from Cape Kennedy
2.	154 seconds - first stage burnout
3.	550 seconds - second stage burnout at 100 nautical mile parking orbit
4.	Period of 100 nautical mile circular orbit is 87.81 minutes
5.	Start S-IV B stage at desired nodal crossing to effect Hohmann transfer
6.	5.257 hours is time required to obtain an equatorial synchronous altitude of 19 327 nautical miles

TABLE II.- ELECTRON DOSES AT 19 237 NAUTICAL MILES
FOR A 34-DAY MISSION

	Skin dose, in rem, from -	
Shielding	Primaries	Bremsstrahlung
Laboratory	51.6	3.0
Command module	1.2	12.4

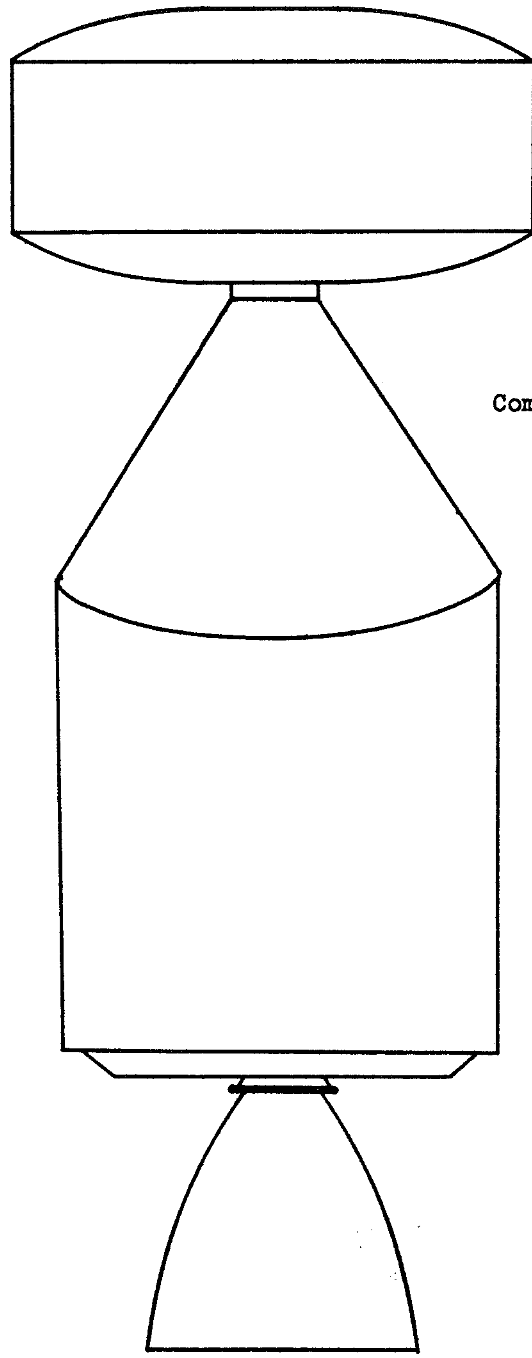

Figure 1 - Proposed Configuration of Apollo-X Spacecraft

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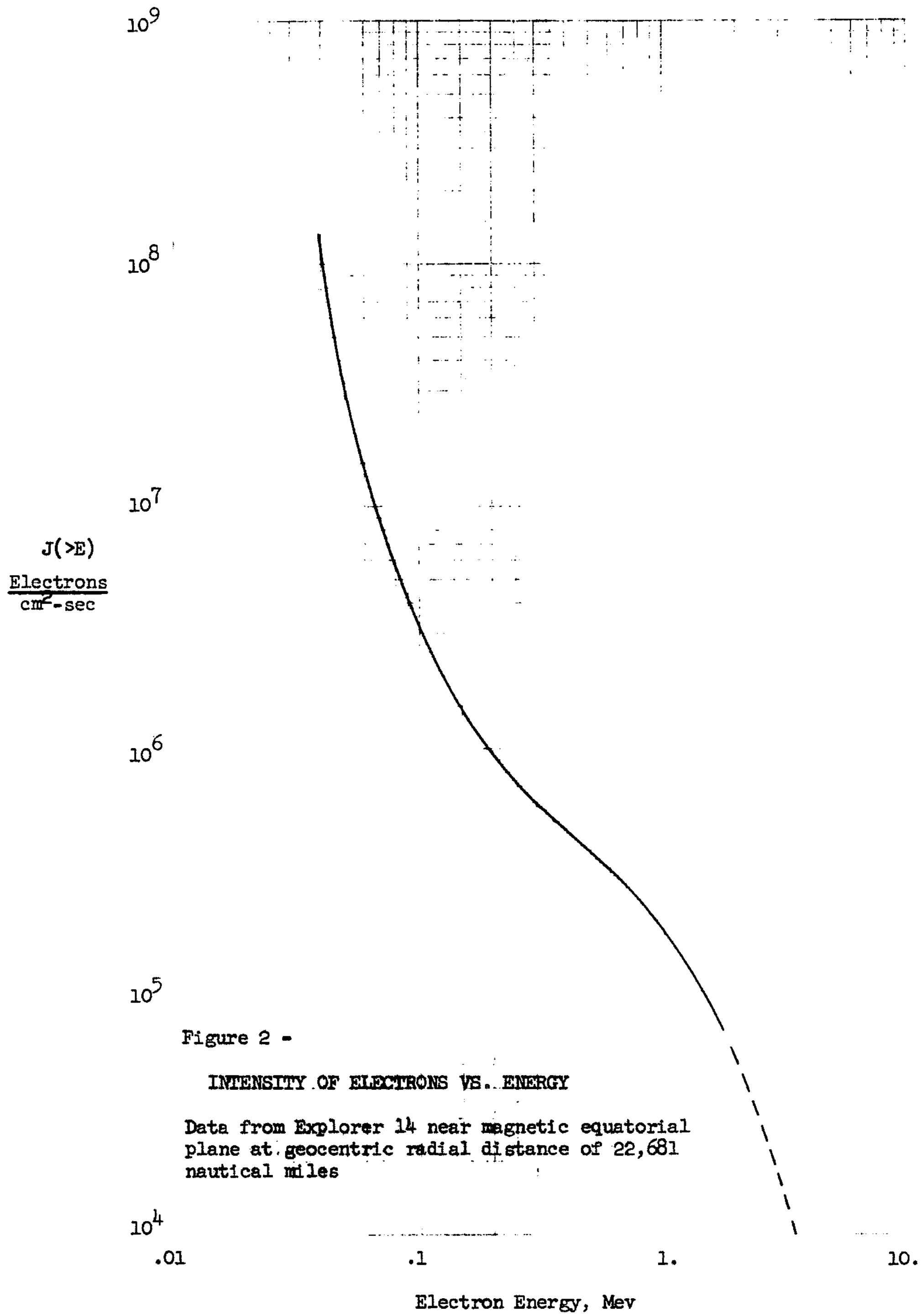

Figure 2 -

INTENSITY OF ELECTRONS VS. ENERGY

Data from Explorer 14 near magnetic equatorial plane at geocentric radial distance of 22,681 nautical miles

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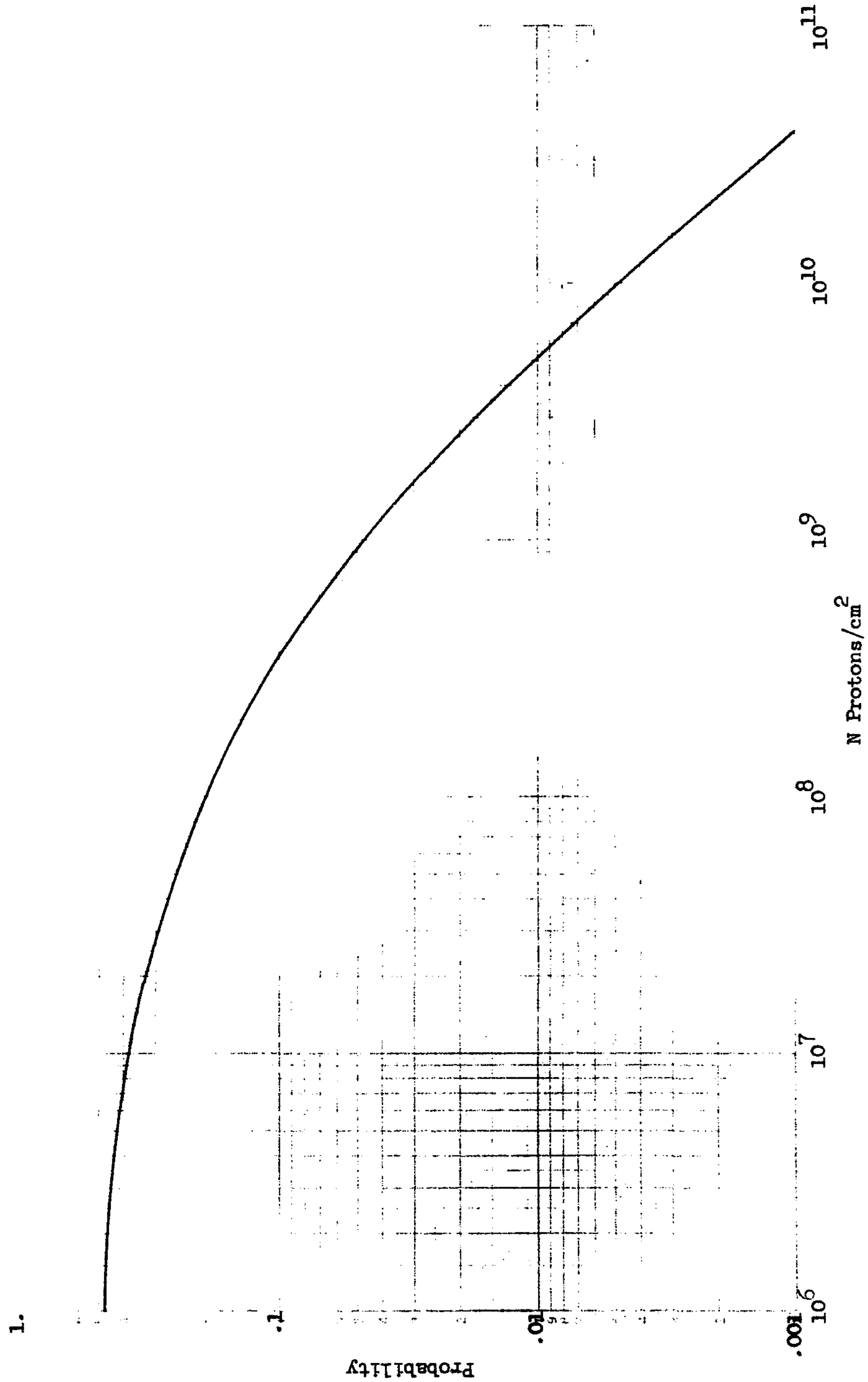

Figure 3 - Probability of encountering ≥N Protons/cm^2 (>30 Mev) vs. N in a 34-day mission

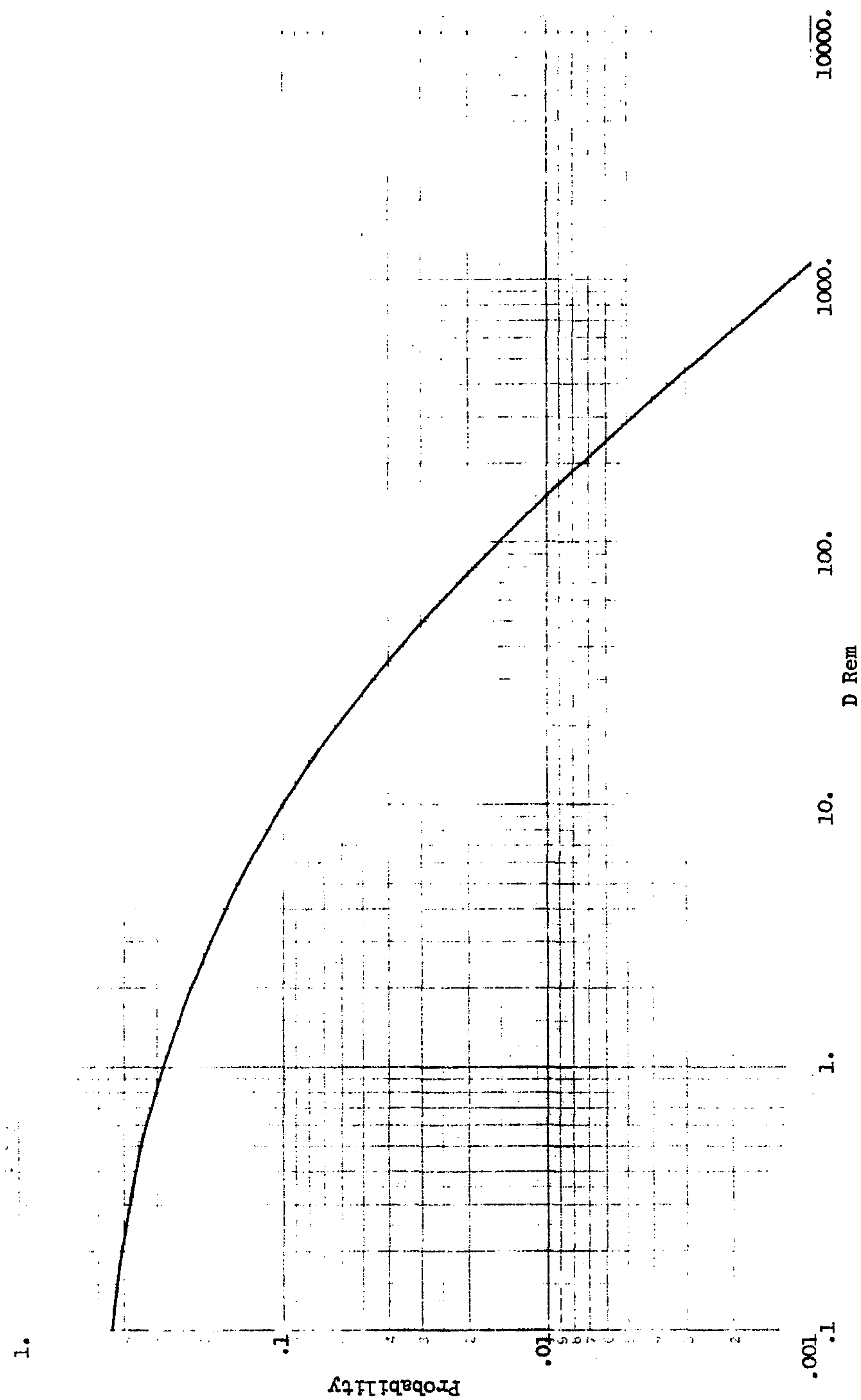

Figure 4 - Probability of Receiving ≥D rem from Solar Particles in Apollo-X Command Module vs. D. Mission Length = 34 days